IAEA
SAFETY
STANDARDS
SERIES

Decommissioning of Nuclear Power Plants and Research Reactors

SAFETY GUIDE

No. WS-G-2.1

INTERNATIONAL
ATOMIC ENERGY AGENCY
VIENNA

IAEA SAFETY RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish standards of safety for protection against ionizing radiation and to provide for the application of these standards to peaceful nuclear activities.

The regulatory related publications by means of which the IAEA establishes safety standards and measures are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety, and also general safety (that is, of relevance in two or more of the four areas), and the categories within it are **Safety Fundamentals**, **Safety Requirements** and **Safety Guides.**

Safety Fundamentals (blue lettering) present basic objectives, concepts and principles of safety and protection in the development and application of nuclear energy for peaceful purposes.

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The IAEA's safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The standards are binding on the IAEA for application in relation to its own operations and to operations assisted by the IAEA.

Information on the IAEA's safety standards programme (including editions in languages other than English) is available at the IAEA Internet site

www.iaea.org/ns/coordinet

or on request to the Safety Co-ordination Section, IAEA, P.O. Box 100, A-1400 Vienna, Austria.

OTHER SAFETY RELATED PUBLICATIONS

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DECOMMISSIONING OF NUCLEAR POWER PLANTS AND RESEARCH REACTORS

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world''.

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FOREWORD

by Mohamed ElBaradei
Director General

One of the statutory functions of the IAEA is to establish or adopt standards of safety for the protection of health, life and property in the development and application of nuclear energy for peaceful purposes, and to provide for the application of these standards to its own operations as well as to assisted operations and, at the request of the parties, to operations under any bilateral or multilateral arrangement, or, at the request of a State, to any of that State's activities in the field of nuclear energy.

The following advisory bodies oversee the development of safety standards: the Advisory Commission on Safety Standards (ACSS); the Nuclear Safety Standards Advisory Committee (NUSSAC); the Radiation Safety Standards Advisory Committee (RASSAC); the Transport Safety Standards Advisory Committee (TRANSSAC); and the Waste Safety Standards Advisory Committee (WASSAC). Member States are widely represented on these committees.

In order to ensure the broadest international consensus, safety standards are also submitted to all Member States for comment before approval by the IAEA Board of Governors (for Safety Fundamentals and Safety Requirements) or, on behalf of the Director General, by the Publications Committee (for Safety Guides).

The IAEA's safety standards are not legally binding on Member States but may be adopted by them, at their own discretion, for use in national regulations in respect of their own activities. The standards are binding on the IAEA in relation to its own operations and on States in relation to operations assisted by the IAEA. Any State wishing to enter into an agreement with the IAEA for its assistance in connection with the siting, design, construction, commissioning, operation or decommissioning of a nuclear facility or any other activities will be required to follow those parts of the safety standards that pertain to the activities to be covered by the agreement. However, it should be recalled that the final decisions and legal responsibilities in any licensing procedures rest with the States.

Although the safety standards establish an essential basis for safety, the incorporation of more detailed requirements, in accordance with national practice, may also be necessary. Moreover, there will generally be special aspects that need to be assessed by experts on a case by case basis.

The physical protection of fissile and radioactive materials and of nuclear power plants as a whole is mentioned where appropriate but is not treated in detail; obligations of States in this respect should be addressed on the basis of the relevant instruments and publications developed under the auspices of the IAEA. Non-

radiological aspects of industrial safety and environmental protection are also not explicitly considered; it is recognized that States should fulfil their international undertakings and obligations in relation to these.

The requirements and recommendations set forth in the IAEA safety standards might not be fully satisfied by some facilities built to earlier standards. Decisions on the way in which the safety standards are applied to such facilities will be taken by individual States.

The attention of States is drawn to the fact that the safety standards of the IAEA, while not legally binding, are developed with the aim of ensuring that the peaceful uses of nuclear energy and of radioactive materials are undertaken in a manner that enables States to meet their obligations under generally accepted principles of international law and rules such as those relating to environmental protection. According to one such general principle, the territory of a State must not be used in such a way as to cause damage in another State. States thus have an obligation of diligence and standard of care.

Civil nuclear activities conducted within the jurisdiction of States are, as any other activities, subject to obligations to which States may subscribe under international conventions, in addition to generally accepted principles of international law. States are expected to adopt within their national legal systems such legislation (including regulations) and other standards and measures as may be necessary to fulfil all of their international obligations effectively.

PREFACE

Radioactive waste is produced in the generation of nuclear power and the use of radioactive materials in industry, research and medicine. The importance of the safe management of radioactive waste for the protection of human health and the environment has long been recognized, and considerable experience has been gained in this field.

The IAEA's Radioactive Waste Safety Standards Programme aimed at establishing a coherent and comprehensive set of principles and requirements for the safe management of waste and formulating the guidelines necessary for their application. This is accomplished within the IAEA Safety Standards Series in an internally consistent set of publications that reflect an international consensus. The publications will provide Member States with a comprehensive series of internationally agreed publications to assist in the derivation of, and to complement, national criteria, standards and practices.

The Safety Standards Series consists of three categories of publications: Safety Fundamentals, Safety Requirements and Safety Guides. With respect to the Radioactive Waste Safety Standards Programme, the set of publications is currently undergoing review to ensure a harmonized approach throughout the Safety Standards Series.

This Safety Guide addresses the subject of decommissioning of nuclear power plants and research reactors. It is intended to provide guidance to national authorities and operating organizations for the planning and safe management of the decommissioning of such installations.

This Safety Guide has been prepared through a series of Consultants and Technical Committee meetings. It supersedes former Safety Series publications Nos 52, 74 and 105.

EDITORIAL NOTE

An appendix, when included, is considered to form an integral part of the standard and to have the same status as the main text. Annexes, footnotes and bibliographies, if included, are used to provide additional information or practical examples that might be helpful to the user.

The safety standards use the form 'shall' in making statements about requirements, responsibilities and obligations. Use of the form 'should' denotes recommendations of a desired option.

The English version of the text is the authoritative version.

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. This Safety Guide is part of a set of publications within the framework of the IAEA Radioactive Waste Safety Standards Programme, which addresses all the important areas of radioactive waste safety. This set includes Safety Fundamentals [1], Safety Requirements and Safety Guides in the old IAEA Safety Series and IAEA Safety Standards Series.

1.2. Safety requirements for the decommissioning of nuclear power plants and research reactor facilities are addressed in the Safety Requirements: Predisposal Management of Radioactive Waste Including Decommissioning [2]. Other IAEA Safety Standards provide additional relevant safety requirements [3–9].

1.3. A large number of ageing reactors will be facing shutdown in the near future. In the past, decommissioning of nuclear power plants and research reactors was performed in a case by case manner using the same framework of regulations as applied during the operational period of a reactor. In order to provide a consistent and harmonious approach to the decommissioning of nuclear reactor installations, as well as to incorporate lessons learned from previous decommissioning efforts, Member States have expressed the need for decommissioning guidance within the context of an internationally accepted programme of radioactive waste safety publications.

1.4. This Safety Guide provides recommendations, on the basis of international experience, to assist in fulfilling the basic requirements for decommissioning as set out in the above mentioned Safety Requirements [2].

OBJECTIVE

1.5. The objective of this Safety Guide is to provide guidance to national authorities, including regulatory bodies, and operating organizations to ensure that the decommissioning process for nuclear power plants and research reactors is conducted in a safe and environmentally acceptable manner.

SCOPE

1.6. The provisions of this Safety Guide apply to nuclear power plants and research reactors and their associated sites. A separate Safety Guide addresses the decommissioning of medical, industrial and research facilities [10].

1.7. This Safety Guide mainly addresses the radiological hazards resulting from the activities associated with the decommissioning of nuclear reactors, primarily with decommissioning after planned final shutdown. Many of the provisions are also applicable to decommissioning after an abnormal event that has resulted in serious plant damage or contamination. In this case, this Safety Guide may be used as a basis for developing special decommissioning provisions, although additional considerations will be necessary.

1.8. Non-radiological hazards, such as those due to potential fire sources or those resulting from the release of asbestos material, can also arise during decommissioning activities. This Safety Guide does not explicitly address these hazards, but it is important that they be given due consideration during the planning process and in a risk analysis.

STRUCTURE

1.9. Issues that are essential to the decommissioning of nuclear power plants and research reactors are outlined in Section 2. The process for selecting the proper decommissioning option is discussed in Section 3. The considerations at the design, construction and operational phases of the installation lifetime which facilitate decommissioning are reviewed in Section 4. Decommissioning planning, safety assessment and financial assurance are addressed in Section 5. Tasks which are critical to decommissioning because of their complexity and/or their relevance to key safety issues are explained in Section 6. The overall management of the decommissioning process is detailed in Section 7. Completion of decommissioning and the contents of the final decommissioning report are discussed in Section 8.

1.10. Annex I provides an example of the contents of a final radiological survey report. Annex II presents an example of documented plans and management systems for the implementation of decommissioning.

2. KEY ISSUES SPECIFIC TO DECOMMISSIONING

GENERAL

2.1. The term decommissioning refers to administrative and technical actions taken to allow removal of some or all of the regulatory controls from a nuclear facility (except for a repository, which is, by definition, subject to closure and not decommissioning). These actions involve decontamination, dismantling and removal of radioactive materials, waste, components and structures. They are carried out to achieve a progressive and systematic reduction in radiological hazards and are taken on the basis of preplanning and assessment to ensure safety during decommissioning operations.

2.2. The time period to the decommissioning activities for nuclear power plants and research reactors may typically range from a few years to decades (for example, to allow for radioactive decay). As a consequence, decommissioning may be carried out in one continuous operation following shutdown or in a series of discrete operations over time (i.e. phased decommissioning).

2.3. Decommissioning may include the phased release of parts of the nuclear installation or of the site from regulatory control, before the decommissioning process for the entire installation or site is complete. In the event that a part of the installation is being decommissioned, this Safety Guide only applies to the decommissioning activities. However, the potential safety implications with respect to the interaction between any decommissioning work and any continuing nuclear installation operations need to be addressed on a case by case basis.

2.4. Subject to national legal and regulatory requirements, a nuclear installation or its remaining parts may also be considered decommissioned if incorporated into a new or existing facility, or even if the site at which it is located is still under regulatory or other institutional control. This could apply, for example, to the decommissioning of a nuclear installation located on a multifacility site.

2.5. There are many factors that have to be addressed to ensure the safety of nuclear reactors during the operational phase. Some of the factors will continue to apply during decommissioning, but decommissioning gives rise to issues that are in some respects different from those prevailing during the operation of the installation. These issues need to be considered in an appropriate way to ensure overall safety during decommissioning.

RESPONSIBILITIES

2.6. When a nuclear reactor is taken out of service, responsibility for the installation may be transferred to a different organization, which becomes the operating organization of the installation for the decommissioning phase. The operating organization of the installation undergoing decommissioning is ultimately responsible for the safety of the installation during the decommissioning operations. For such transference to be effective, a complete set of records and drawings should be maintained and passed on to the new operating organization. Decommissioning activities may involve many different organizations, including contractors and subcontractors which may not be familiar with nuclear installations, and it is of prime importance to define clearly the responsibilities between the different organizations.

2.7. The operating organization should develop a public information programme to provide information on the decommissioning project.

REGULATORY FRAMEWORK

2.8. The regulatory framework of a country should include provision for the decommissioning of nuclear installations, in particular nuclear reactors. National regulatory authorities should provide guidance on radiological criteria for the removal of regulatory controls over the decommissioned installations and sites and should ensure that an adequate system is in place for properly managing the removal of controls.

2.9. Some activities relevant to decommissioning may be carried out after shutdown of the nuclear installation under licence provisions carried over from the operating phase. Such activities may include management of operational waste, measurements to determine the radioactive inventory, removal from the installation of nuclear fuel or other materials related to the original operation, and preliminary decontamination.

2.10. In the absence of regulations addressing decommissioning, decommissioning activities should be undertaken on a case by case basis under existing regulations for operational installations. In such cases, the operating organization should consult the regulatory body in the development and implementation of the decommissioning plan. In the plan, the operating organization should be required to demonstrate how compliance with the regulations will be achieved.

2.11. The regulatory control of decommissioning can be done by a single overall licence, by separate licences, or by direct control by a regulatory body, whichever is

considered to be most appropriate in the circumstances. Within the scope of the regulatory infrastructure, the regulatory body should review and, as appropriate, approve the selected decommissioning option, decommissioning plans, quality assurance programmes and other submissions related to the decommissioning of a nuclear reactor. Moreover, the operating organization should report to the regulatory body on a scheduled basis, as stipulated in the regulatory control mechanism (e.g. licence), any safety related information (e.g. monitoring data, radiological surveys). In the case of abnormal occurrences, the operating organization should report, in a timely fashion, those data that are necessary to evaluate safety during such events.

SAFETY

2.12. At all phases of decommissioning, workers, the public and the environment should be properly protected from hazards resulting from the decommissioning process. A thorough safety assessment of the hazards involved during decommissioning (including accident analysis, where necessary) should be conducted to define protective measures, as part of a defence in depth system that takes into account the specifics of decommissioning. In some cases, such measures may be different from those in place during the operation of the installation.

2.13. Decommissioning of nuclear installations often involves the removal, at an early stage, of significant quantities of radioactive material, including fuel and operational waste. Even after this step, the total contamination and activation of the installation is significant and has to be taken into account in the safety assessment.

2.14. The implementation of particular activities such as decontamination, cutting and handling of large equipment, and the progressive dismantling or removal of some existing safety systems are also of importance. These activities have the potential for creating new hazards. An important objective during decommissioning is, therefore, that the safety aspects of these decommissioning activities, such as the removal of existing safety systems, be adequately assessed and managed, so as to mitigate any potential exposure. Integrity of spent fuel, when still stored on-site in a fuel pool, should be considered and maintained. Fire protection and suppression for the complete site should be included in the decommissioning plan.

PLANNING

2.15. Experience has shown that, provided that these actions are properly planned and implemented, decommissioning of nuclear reactors and management of the

resulting radioactive materials can be accomplished without undue risk to or radiological impacts on workers, the public or the environment. Decommissioning can be facilitated by planning and preparatory work undertaken during the entire lifetime of the nuclear installation. These actions are intended to minimize the eventual occupational and environmental impacts which can occur during the active and passive processes undertaken during decommissioning (see Section 5).

2.16. Decommissioning should be considered in the design and operation phases. However, many of the nuclear power plants and research reactors have been operating for many years, and decommissioning may not have been considered at the design stage. The planning of decommissioning for such installations should recognize this, and planning should start as early as possible. Most of the guidance given in this Safety Guide will be applicable to this situation.

CONSIDERATIONS FOR RADIATION PROTECTION AND ENVIRONMENTAL PROTECTION

2.17. Consideration must be given to the radiation protection of both workers and members of the public, not only during the course of decommissioning but also as a result of any subsequent occupancy of the decommissioned site. National radiation protection requirements should be established, with due regard to the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (BSS) [4].

2.18. During decommissioning of nuclear power plants or research reactors, radioactive and non-radioactive pollutants may be discharged to the environment. These discharges should be controlled in compliance with appropriate national regulations. Guidance on the regulatory control of discharges of radioactive effluents to the environment has also been developed in Refs [4, 11, 12].

2.19 Guidance on radiological criteria for the removal of regulatory control from materials, equipment and sites is being developed in other IAEA Safety Standards Series publications.

WASTES

2.20. Decommissioning of nuclear reactors invariably involves the generation of large amounts of radioactive wastes. In the course of decommissioning, waste will be generated in forms that are different from materials and wastes of the types routinely

handled during the operational phase of a nuclear power plant or research reactor. Subject to safety considerations, "generation of radioactive waste shall be kept to the minimum practicable" [1]. For example, appropriate decontamination and dismantling techniques and the reuse or recycling of materials can reduce the waste inventory.

3. SELECTION OF A DECOMMISSIONING OPTION

GENERAL

3.1. A specific decommissioning option will, among other things, define the timing and the sequencing of decommissioning activities. Decommissioning options can range from immediate dismantling and removal of all radioactive materials from the site, allowing unrestricted release, to an option of in situ disposal involving encapsulation of the reactor and subsequent restriction of access.

3.2. An intermediate option consists of a minimum degree of early dismantling and of conversion of the plant to safe enclosure, before eventual dismantling. Similarly, options can include the dismantling of some parts of the plant, usually externally accessible areas, while placing others, particularly the reactor core, into a safe enclosure mode. Most options consider the safe removal of the fuel and operational waste early in the decommissioning phase in order to obtain a significant reduction in the hazard associated with the installation.

3.3. The selection of a safe enclosure option for a defined period of time is known as deferred dismantling. If the chosen option is deferred dismantling, studies of appropriate methods and approaches should still be conducted in preparation for the eventual dismantling.

3.4. An evaluation of the various decommissioning options should be performed by considering a wide range of issues, with special emphasis on the balance between the safety requirements and the resources available at the time of implementing decommissioning. Cost–benefit or multiattribute type analyses provide systematic means for such an evaluation. These analyses should utilize realistic estimates of both costs and radiation doses. It should be ensured that the selected option meets all the applicable safety requirements. The selection of a preferred decommissioning option should be made by analysing components such as:

(a) compliance with laws, regulations and standards which should be applied during decommissioning;
(b) characterization of the installation, including the design and operational history as well as the radiological inventory after final shutdown and how this changes with time;
(c) safety assessment of the radiological and non-radiological hazards;
(d) the physical status of the nuclear installation and its evolution with time, including, if applicable, an assessment of the integrity of buildings, structures and systems for the anticipated duration of the deferred dismantling;
(e) adequate arrangements for waste management, such as storage and disposal;
(f) adequacy and availability of financial resources required for the safe implementation of the decommissioning option;
(g) availability of experienced personnel, especially staff of the former operating organization, and proven techniques, including decontamination, cutting and dismantling, as well as remote operating capabilities;
(h) lessons learned from previous, similar decommissioning projects;
(i) the environmental and socioeconomic impact, including public concerns about the proposed decommissioning activities; and
(j) the anticipated development and use of the installation and the area adjacent to the site.

This list contains many issues that have greater or lesser significance, depending on the specific circumstances of decommissioning in each country. To assist the development of options, a number of these components are further developed in the paragraphs below.

SAFETY

3.5. Radiological and non-radiological hazards should be identified in a formal safety assessment (including accident analysis, where necessary), leading to the provision of appropriate protective measures to ensure the safety of workers and the public and protection of the environment and to ensure that the relevant criteria are met.

3.6. Decommissioning may involve operations that may not be normal during the operation of the installation, and the significance of non-radiological hazards may be increased after the fuel and the operational waste are removed. The problem of ageing of the reactor's components becomes important when deferred decommissioning is being considered and should be addressed in the safety assessment.

3.7. The safety assessment will aid in the identification of engineering and administrative arrangements that should be in place to ensure the safety of the

decommissioning process and will aid in the choice of a particular decommissioning option. The protective measures may require the established systems for operational installations to change, but the acceptability of such changes should be clearly justified in the safety assessment.

WASTE MANAGEMENT

3.8. The implications for waste management should be considered in the options for decommissioning. The volumes, activity and types of waste generated can depend on the timing and the techniques chosen. Appropriate and safe waste management arrangements should be available, including disposal or storage routes.

COST CONSIDERATIONS

3.9. When considering decommissioning options, all activities described in the decommissioning plan should be included in the estimation of the cost for decommissioning. These activities include planning and engineering during the post-operation phases, development of a specific technology, decontamination and dismantling, conducting a final survey and management of radioactive waste, including disposal. The cost of maintenance, surveillance and physical protection of the nuclear installation should also be taken into account, especially if any phase of decommissioning is deferred for an extended period.

AVAILABILITY OF EXISTING EXPERTISE

3.10. The availability and utilization of plant specific expertise should be considered in choosing a decommissioning option; for example, retention and utilization of key personnel familiar with site specific conditions. This expertise could decrease the potential for events such as industrial accidents or overexposures and may help to reduce problems associated with loss of a corporate memory, and retraining or recruiting of new personnel. A good system of record keeping for this purpose is important.

CONSIDERATIONS RELATING TO THE PUBLIC

3.11. In making the choice among the different decommissioning strategies, consideration should be given to:

(a) local factors, including the anticipated development and use of land;
(b) local employment considerations; and
(c) visual impact and the public attitude.

4. FACILITATING DECOMMISSIONING

GENERAL

4.1. The requirements for decommissioning should be considered at the design stage for a new reactor installation or as soon as possible for existing installations. The later in the reactor lifetime consideration is given to facilitating decommissioning, the more difficult and costly decommissioning may become. This may be due to a lack of adequate records and information, the need to install or modify equipment, the increased complexity of decommissioning activities, and the incurring of unnecessary doses as a result of aspects of the design interfering with decommissioning.

CONSIDERATIONS AT THE DESIGN AND CONSTRUCTION PHASE

4.2. A baseline background radiological characterization of the site for the proposed facility and the facility itself (as normally required for operation) should be undertaken. This should include appropriate radiological monitoring of the site for the proposed facility and its surroundings to establish baseline levels of radiation for assessing the future impact of the reactor on the site; this may be critical to future decisions on the acceptability of decommissioning proposals [8]. Quantification of the natural activity in building materials used for construction may prove useful in determining future clearance and target cleanup levels in the installation during decommissioning.

4.3. A thorough review of design features, from the viewpoint of facilitating decommissioning, should be performed during the design stage of the reactor installation. In general, design features which assist maintenance and inspection during the operational lifetime of the reactor will also assist decommissioning. Specific factors should include:

(a) Careful selection of materials to:
  — reduce activation;
  — minimize the spread of activated corrosion products;

— ensure that surfaces are easy to decontaminate; and
— minimize the use of potentially hazardous substances (e.g. oils, flammable and chemically hazardous materials and fibrous insulations);

(b) Optimization of the plant's design, layout and access routes to facilitate:
— the removal of large components;
— easy detachment and remote removal of significantly activated components;
— future installation of decontamination and waste handling equipment;
— decontamination or removal of embedded components such as pipes and drains; and
— control of radioactive material within the installation.

The inclusion of design features to assist decommissioning would be aided by the use of suitable scale models or computer models.

4.4. Full details of the design specification and information relevant to the siting, final design and construction of the reactor installation should be retained as part of the information needed to assist in decommissioning. Essential information required for decommissioning purposes at the end of the operational lifetime of the reactor should be identified. This information should be collected, maintained and revised throughout the operational lifetime of the reactor. The mechanism for doing this should be clearly stated as a responsibility of the operating organization and the regulatory body. Such information may include 'as built' drawings, models and photographs, the construction sequence, piping, details of construction, cable penetrations, repairs or accepted deviations in components and structures, and location of reinforcement bars.

CONSIDERATIONS DURING REACTOR OPERATION

4.5. Accurate and relevant records should be kept of the operating phase of the installation in order to facilitate successful decommissioning. If these records have not been or are not being maintained, such record keeping should be initiated as soon as possible. These records should be configured so that those relevant to decommissioning may be readily identified (e.g. the estimates of the radioactive inventory should be easy to locate and update). In addition to drawings and diagrams, photographic records of the construction and operational phases of the reactor lifetime should be kept. These records should include:

(a) details of the operating history of the reactor, including records of:
— fuel failures and fuel accounting;

— incidents leading to spillage or inadvertent release of radioactive material;
— radiation and contamination survey data, particularly for plant areas that are rarely accessed or especially difficult to access;
— releases that could potentially affect groundwater;
— radioactive inventory; and
— wastes and their location.

(b) details of modifications to the plant and maintenance experience including records of:
— updated 'as built' drawings and photographs, including details of the materials used;
— special repair or maintenance activities and techniques (e.g. effective temporary shielding arrangements or techniques for the removal of large components); and
— details of the design, material composition, and the history and location of all temporary experiments and devices.

4.6. During operations, consideration should be given to minimizing the extent of contamination of structures and surfaces, segregation of different categories of wastes, and avoidance and prompt cleanup of spillages and leaks [4, 9, 13–19]. This should also include maintenance of protective coatings and containment of contaminated materials.

4.7. Experimental irradiation of specimens of selected materials used in the construction of the installation may assist in comparing the measured with the calculated activation levels for estimating the final radioactive inventory.

5. PLANNING AND SAFETY ASSESSMENT FOR DECOMMISSIONING

GENERAL

5.1. Successful decommissioning depends on careful and organized planning. A decommissioning plan should be prepared for each reactor. The extent of such plans, their content and degree of detail required may differ, depending on the complexity and hazard potential of the nuclear installation, and should be consistent with national regulations.

5.2. The operating organization should plan for adequate financial resources to ensure the decommissioning of a nuclear reactor. Especially in the case of deferred decommissioning, where there may be long safe enclosure periods, these financial provisions should be reviewed periodically and adjusted as necessary to allow for inflation and other factors such as technological advances, waste costs and regulatory changes. Responsibility for this review may reside with the operating organization, the regulatory body or other parties, depending on the national legal framework.

5.3. A safety assessment should form an integral part of the decommissioning plan. The operating organization is responsible for preparing the safety assessment and submitting it for review by the regulatory body. The safety assessment should be commensurate with the complexity and potential hazard of the installation and, in case of deferred decommissioning, should take into account the safety of the installation during the period leading up to final dismantling.

5.4. Three stages of planning are envisaged: initial, ongoing and final. For a given reactor, the degree of detail will increase from the initial to the final decommissioning plan. This planning process will result in the production of a decommissioning plan, as described below.

5.5. Records from the siting, design, construction, operation and shutdown are essential to the planning of decommissioning. Although such records need not be explicitly included in the decommissioning plan itself, the process of initial, ongoing and final planning should utilize pertinent records to achieve safety and optimal efficiency in decommissioning.

INITIAL PLANNING

5.6. An initial plan for decommissioning should be prepared and submitted by the operating organization in support of the licence application for the construction of a new reactor. Although the level of detail in the initial plan will necessarily be lower than that in the final decommissioning plan, many of the aspects listed in para. 5.11 should be considered in a conceptual fashion. A generic study showing the feasibility of decommissioning may suffice for this plan, particularly in standardized installations. Depending on applicable regulations, the plan should address the costs and the means of financing the decommissioning work.

5.7. In cases where an operational plant does not have an initial plan for decommissioning, a decommissioning plan reflecting the operational status of the installation should be prepared without undue delay.

ONGOING PLANNING

5.8. During the operation of a reactor, the decommissioning plan should be reviewed, updated and made more comprehensive with respect to technological developments in decommissioning, incidents that may have occurred, including abnormal events, amendments in regulations and government policy, and, where applicable, cost estimates and financial provisions. The decommissioning plan should evolve with respect to safety considerations, based on operational experience and on information reflecting improved technology. All significant systems and structural changes during plant operation should be reflected in the process of ongoing planning for decommissioning.

FINAL PLANNING

5.9. When the timing of the final shutdown of a nuclear reactor is known, the operating organization should initiate detailed studies and finalize proposals for decommissioning. Following this, the operating organization should submit an application containing the final decommissioning plan for review and approval by the regulatory body. The decommissioning plan may require amendments or further refinements as decommissioning proceeds, and may require further regulatory approval.

5.10. If the selected decommissioning option results in phased decommissioning — with significant periods of time between phases — a higher level of detail for items identified in para. 5.11 may be required for the next phase being executed. As a result of executing an individual phase of the decommissioning, some modification to the planning for subsequent phases may be needed. In such cases, subsequent sections of the decommissioning plan may require updating and reviewing.

5.11. The experience from previous decommissioning should be appropriately taken into account as a matter of principle. The following list of items to be considered for the final decommissioning plan should thus be updated whenever previous decommissioning experience permits:

(a) a description of the nuclear reactor, the site and the surrounding area that could affect, and be affected by, decommissioning;
(b) the life history of the nuclear reactor, reasons for taking it out of service, and the planned use of the nuclear installation and the site during and after decommissioning;
(c) a description of the legal and regulatory framework within which decommissioning will be carried out;

(d) explicit requirements for appropriate radiological criteria for guiding decommissioning;
(e) a description of the proposed decommissioning activities, including a time schedule;
(f) the rationale for the preferred decommissioning option, if selected;
(g) safety assessments and environmental impact assessments, including the radiological and non-radiological hazards to workers, the public and the environment; this will include a description of the proposed radiation protection procedures to be used during decommissioning;
(h) a description of the proposed environmental monitoring programme to be implemented during decommissioning;
(i) a description of the experience, resources, responsibilities and structure of the decommissioning organization, including the technical qualification/skills of the staff;
(j) an assessment of the availability of special services, engineering and decommissioning techniques required, including any decontamination, dismantling and cutting technology as well as remotely operated equipment needed to complete decommissioning safely;
(k) a description of the quality assurance programme;
(l) an assessment of the amount, type and location of residual radioactive and hazardous non-radioactive materials in the nuclear reactor installation, including calculational methods and measurements used to determine the inventory of each;
(m) a description of the waste management practices, including items such as:
— identification and characterization of sources, types and volumes of waste;
— criteria for segregating materials;
— proposed treatment, conditioning, transport, storage and disposal methods;
— the potential to reuse and recycle materials, and related criteria; and
— anticipated discharges of radioactive and hazardous non-radioactive materials to the environment;
(n) a description of other applicable important technical and administrative considerations such as safeguards, physical security arrangements and details of emergency preparedness;
(o) a description of the monitoring programme, equipment and methods to be used to verify that the site will comply with the release criteria;
(p) details of the estimated cost of decommissioning, including waste management, and the source of funds required to carry out the work; and
(q) a provision for performing a final confirmatory radiological survey at the end of decommissioning.

5.12. Decommissioning may be carried out in a sequence of operations separated by one or more periods of time (i.e. phased decommissioning). Some of these periods

(i.e. decommissioning phases) may consist of inactive, safe enclosure. In such cases of multiple decommissioning phases, the operating organization should submit to the regulatory body a description of:

(a) the proposed surveillance and maintenance programme for the buildings, structures and safety related operational systems;
(b) existing or new systems or programmes necessary for maintaining the installation under proper control, such as engineered barriers, ventilation, drainage and environmental/safety monitoring;
(c) systems to be installed or replaced to carry out deferred dismantling;
(d) the proposed frequency at which the above items would be reviewed; and
(e) the number of staff needed and their qualifications, during any period of deferment.

5.13. In the case of installation shutdown without a decommissioning plan, such a plan should be promptly prepared.

SAFETY ASSESSMENT FOR DECOMMISSIONING A NUCLEAR REACTOR

5.14. At all phases of decommissioning, workers, the public and the environment should be protected from hazards associated with the decommissioning processes. Radiological and non-radiological hazards involved in the proposed decommissioning activities should be identified in a formal safety assessment leading to the definition of protective measures to ensure the safety of workers, the public and the environment, i.e. to meet specified criteria. The protective measures may require the established safety systems for operational installations to change, but the acceptability of such changes should be clearly justified in the safety assessment.

Radioactive materials inventory

5.15. The removal of fuel and the early treatment of operational waste are generally considered during the end of the operational phase or at an early stage in the decommissioning process. This reduces the radioactive inventory significantly. The activity remaining is generally associated with, for example, activation products from reactor operations, irradiation devices or contamination associated with primary/secondary coolant circuits, fuel routes and cooling ponds. The irradiation devices require special attention during the planning process owing to the difficulty of removal and disposal.

5.16. In the event that fuel is not removed as part of operations or early in the decommissioning process, the safety assessment should consider the implications

of this large inventory of radioactive material for the safety of the decommissioning activities. When spent fuel has been removed as well as operational waste, it is also important to locate and estimate the quantities of residual radionuclides present and their physical and chemical form. Special attention must be given to the potential for contamination due to the production and release of dust and aerosols of radioactive liquids, and of large quantities of waste generated during decommissioning operations.

Radiation protection

5.17. Decommissioning should be carried out in compliance with specified national requirements for radiation protection and other safety and environmental protection requirements.

Deferred dismantling

5.18. The half-lives of radionuclides that are present in significant amounts should be considered in determining the length of time for which various decommissioning activities might be deferred so as to fulfil the appropriate radiological criteria. There may be benefits to be gained from deferred dismantling of nuclear reactors by having a period of safe enclosure. Deferral of dismantling and demolition may reduce the quantities of radioactive waste produced and reduce radiation exposure to site personnel. In addition, this delay in dismantling may permit technological improvements in the future to be incorporated into the process when decommissioning activities are resumed. However, this option could result in the loss of trained and knowledgeable workers.

5.19. There may be additional disadvantages in delaying dismantling and demolition. If deferred dismantling is being considered for a prolonged period of time, due regard should be given to gradual deterioration of the structures, systems and components designed to act as barriers between the radionuclide inventory and the environment. This deterioration may also apply to systems that could be necessary during plant dismantling. The safety assessment should consider the requirement for maintenance, tests of requalification or replacement of these systems (mechanical handling systems, ventilation, power supply and waste handling systems) and the implications of deterioration for safety should be evaluated. To implement safe enclosure, new systems and structures may have to be installed or existing systems and structures modified. The integrity of these new systems and structures should be assessed over the prolonged period of safe enclosure (deferred dismantling). Delays in decommissioning may also lead to an increased liability resulting from possible exposures or from releases and migration of residual radionuclides.

5.20 If deferred dismantling is instituted, the safety documentation and decommissioning plans should be periodically reviewed to ensure that they represent current installation conditions.

Non-radiological safety

5.21. The safety assessment may identify a number of significant non-radiological hazards during the decommissioning phase that are not normally encountered during the operational phase of a reactor. These include, for example, hazardous materials that may be used during decontamination, dismantling and demolition activities, and the lifting and handling of heavy loads. Most of these non-radiological hazards will be covered by regulations, but a good safety culture will help to ensure that such tasks are carried out safely.

General results of the safety assessment

5.22. The safety assessment should identify the actions that are necessary to ensure continuing safety during all phases of decommissioning. Such actions may be protective measures that are engineered or administrative arrangements that will provide the necessary defence in depth as identified in Ref. [20]. This defence in depth is essential, for example, when actions are taken to break into the containment or during deferred dismantling (safe enclosure). The elements of defence in depth will vary and evolve as progress is made in the decommissioning of the installation.

FINANCIAL ASSURANCE FOR DECOMMISSIONING

5.23. The cost of decommissioning should reflect all activities described in the decommissioning plan, for example planning and engineering during the post-operation phases, the development of a specific technology, decontamination and dismantling, conducting a final survey, and management of radioactive waste. The cost of maintenance, personnel qualification, surveillance and physical security of the reactor installation should be taken into account, especially if any phase of decommissioning is deferred for an extended period of time.

5.24. In order to provide the necessary confidence that the resources will be available to maintain radiation and environmental protection during decommissioning, provision for allocating resources should be established early in the planning of the nuclear power plant design. According to the legal framework, such a mechanism should be established before operation in order to secure the funds needed for decommissioning. The mechanism should be sufficiently robust to provide for decommissioning

needs in the event of premature shutdown of the reactor installation. Irrespective of the type of financial mechanisms used, provision for premature decommissioning should be in place, should it be needed.

5.25. For existing reactor installations with no financial assurance mechanism for decommissioning, such a mechanism should be established without undue delay.

6. CRITICAL TASKS OF DECOMMISSIONING

INITIAL CHARACTERIZATION OF THE INSTALLATION

6.1. A survey of radiological and non-radiological hazards is an important input for the safety assessment and for implementing a safe approach during the work and should be conducted to identify the inventory and location of radioactive and other hazardous materials. In planning and implementing surveys, use should be made of existing records and operating experience. A characterization report should be prepared which documents the information and data obtained during the characterization process. The report should be retained as part of the official records of the installation.

6.2. An adequate number of radiation and contamination surveys should be conducted to determine the radionuclides, maximum and average dose rates, and contamination levels of inner and outer surfaces of structures or components throughout the reactor installation. For completeness, contamination in shielded or self-shielded components, such as inside pipes and pumps, should be characterized. Results of such surveys will aid in the preparation of radiation and contamination maps. Furthermore, special surveys to determine the penetration depth and the extent of contamination may be required to assist in the selection of appropriate procedures for decontamination or dismantling. For activated components, calculations should be used together with selective verification sampling.

6.3. An inventory of all hazardous chemicals present in the installation should be conducted. Hazardous materials such as asbestos require special consideration to prevent harm to human health. Substances such as oils found in nuclear reactors in general, or sodium residues found in fast breeder reactors, may present significant risk of fire or explosion which has to be dealt with in an appropriate manner.

FUEL REMOVAL

6.4. The removal of spent fuel from the reactor installation at the end of its operational lifetime should preferably be performed as part of operations or as one of the initial activities in decommissioning. Its timely removal from the installation is beneficial and will simplify monitoring and surveillance requirements. The time for fuel removal will vary considerably, depending upon the type and size of the reactor, the condition of the fuel, and also on the constraints for its transport and off-site management. Other activities associated with decommissioning may be conducted concurrently with fuel removal, but potential interference should be evaluated.

6.5. The procedures used for the removal, storage and shipment of fuel would be expected to be the same as those used during normal operation. In the case of reactors where not all of the fuel is routinely removed from the core during maintenance or refuelling outages, only assessed configurations of partly fuelled cores should be used, to avoid criticality of unusual core geometries and to ensure adequate cooling of fuel elements. While the fuel remains in the reactor installation, it should be stored in such a way as to control any risk to the public and to the site personnel.

6.6. Where on-site interim storage facilities for spent fuel are utilized, care should be taken with respect to possible interference with future decommissioning activities at the reactor installation.

6.7. In some reactors, stocks of new fuel may be present at the time of final shutdown. Normally, new fuel should be shipped for utilization in similar operating reactors. If such an option is not viable, other arrangements should be made for its safe and secure management.

6.8. Appropriate quality assurance arrangements or checks should be carried out to ensure that all fuel has been removed from the reactor. For those reactors where complete fuel removal cannot be guaranteed, continued safety must be demonstrated for any interim storage period and for subsequent decommissioning activities.

CONTAINMENT MAINTENANCE AND MODIFICATION

6.9. Containment is an important element of defence in depth to prevent the movement of residual radionuclides.

6.10. Care should be taken to retain containment systems as long as necessary and feasible. However, the containment may require changes during decommissioning as radioactive materials (spent fuel and operational waste) are removed from the installations or as the installation is modified, for example, in order to increase accessibility. When containment related barriers or devices are removed or altered in the course of dismantling, acceptable confinement of residual radioactive material should be planned and demonstrated by the operating organization. Similarly, adequate containment should be planned and demonstrated when cutting and dismantling operations are carried out which may give rise to airborne contamination.

6.11. In the case of deferred dismantling, structures and systems may have to perform for longer periods than their accepted design life. This is important for active containment devices. Care should be taken to ensure that proper maintenance is performed and to assess their integrity and efficiency regularly. Similar considerations may also apply to non-radiological hazards that may arise in the installation, including those due to toxic materials, flammable liquids or vapours, heavy metals or asbestos.

DECONTAMINATION

6.12. The term decontamination covers the broad range of activities directed to the removal or reduction of radioactive contamination in or on materials, structures and equipment at a nuclear installation. Decommissioning of a reactor may be aided at certain stages by partial or total decontamination. Decontamination may be applied to internal or external surfaces of components and systems, structural surfaces and the tools employed in decommissioning. The process of decontamination associated with decommissioning can be conducted before, during or after dismantling.

6.13. The objectives of decontamination include:

(a) a reduction of exposures during decommissioning activities;
(b) a minimization of the volume of the categories of material to be classified or disposed of as solid radioactive waste; and
(c) the increase of the possibility of recycle and reuse of equipment, materials or premises.

6.14. A number of decontamination techniques have been developed which may be applicable to decommissioning. International exchanges of information should be encouraged. If necessary, innovative techniques should be demonstrated in mock-up

trials and other simulations. The applicability of these techniques to the particular decommissioning project should be thoroughly assessed before selection.

6.15. Before any decontamination strategy is undertaken or a decontamination technique is selected, an evaluation of its effectiveness should be performed. In order to ensure that exposures are kept as low as reasonably achievable, this evaluation should include:

(a) the target decontamination level;
(b) the estimated doses to workers;
(c) consideration of the possible generation of aerosols;
(d) consideration of the likelihood that available techniques will achieve the target level on particular components;
(e) an ability to demonstrate by measurement that the target level has been reached;
(f) the availability of facilities required for decontamination and their eventual decommissioning;
(g) the cost of the application compared with the expected benefit (e.g. cost of decontamination versus the cost of disposal of original material);
(h) an estimate of the volume, nature, category and activity of any primary and secondary wastes;
(i) consideration of the compatibility of these wastes with existing treatment, conditioning, storage and disposal systems;
(j) any possible deleterious effect of decontamination on equipment and system integrity;
(k) any possible on-site and off-site consequences as a result of decommissioning activities; and
(l) the non-radiological hazards (e.g. the toxicity of solvents used).

DISMANTLING

6.16. There are many available dismantling techniques applicable to reactor decommissioning. Each technique carries some advantages as well as some disadvantages in comparison with others. For example, where remote dismantling is necessary owing to fields of high radiation, thermal cutting methods allow the use of relatively simple holding mechanisms. However, these methods generate large quantities of radioactive aerosols requiring local ventilation with filtration systems; this results in the generation of secondary wastes.

6.17. In contrast, mechanical cutting methods need robust and elaborate holding mechanisms, but these methods usually result in smaller quantities of secondary

wastes. Underwater cutting methods have the advantage of enhanced radiation protection, because of reduced generation of aerosols and the shielding effect of the water. These methods require, however, special tools and control mechanisms which can operate safely underwater, but usually generate secondary wastes in the form of liquid slurry.

6.18. Basic cutting, dismantling and remote operating capabilities have been developed and used. International information exchanges should be encouraged to improve the knowledge of practices. Special tools and devices may be needed during the dismantling. In such cases, these tools and devices should be tested in mock-up trials before their use. The applicability of these techniques to the particular decommissioning project should be thoroughly assessed before selection. Where necessary, maintenance and periodic testing of these tools and devices should be factored into their deployment strategy.

6.19. Selection of methods and techniques to be used in safe dismantling should take into account such aspects as:

(a) the types and characteristics (e.g. size, shape and accessibility) of materials, equipment and systems to be dismantled;
(b) the availability of proven equipment;
(c) the radiation hazards to the worker and the general public, e.g. level of activation and surface contamination, production of aerosols and dose rates;
(d) the environmental conditions of the workplace, e.g. temperature, humidity and atmosphere;
(e) the radioactive waste produced;
(f) the non-radioactive waste produced; and
(g) the requirement for development work.

6.20. Each dismantling task should be analysed to determine the most effective and safe method for its performance. Some considerations are as follows:

(a) equipment should be simple to operate, decontaminate and maintain;
(b) effective methods for controlling airborne radionuclides should be implemented;
(c) there should be effective control of discharges to the environment;
(d) when underwater dismantling and cutting is used, provision should be made for water processing to ensure good visibility and assist in effluent treatment;
(e) the effect of each task on adjacent systems and structures and on other work in progress should be evaluated; and
(f) waste containers, handling systems and routes should be defined before the start of dismantling work.

MAINTENANCE

6.21. Maintenance may be important during deferred decommissioning since part of the safety of the installation may rely on systems that have to retain their capability to perform for extended periods of time. Periodical monitoring of all the safety related components of the installation should be incorporated into the decommissioning plan.

FINAL RADIOLOGICAL SURVEY

6.22. At the completion of the decontamination or dismantling activities, a survey of the residual radionuclides at the reactor site should be performed to demonstrate that the residual activity complies with the criteria set by the national regulatory authority and the decommissioning objectives have been fulfilled. This survey may be carried out in phases, as decommissioning work is completed, to enable parts of the site to be released from regulatory control.

6.23. The survey data should be documented in a final survey report and submitted to the regulatory body. This report should form one of the bases for reuse of the site or for its release from regulatory control. The report should include:

(a) criteria used;
(b) methods and procedures to ensure that the criteria were met; and
(c) measurement data, including appropriate statistical analysis and systematic approaches used.

6.24. The results of the survey should be included in the final decommissioning report. An example of the table of contents of such a final radiological survey report for a nuclear installation is provided in Annex I.

7. MANAGEMENT DURING DECOMMISSIONING

GENERAL

7.1. There are a number of areas of management which should receive consideration during decommissioning. In particular, they should address the potentially extended time-scales which could apply to decommissioning activities.

STAFFING AND TRAINING

7.2. The operating organization should have, or have access to, competent staff to cover the following areas adequately:

(a) safety requirements of the licence;
(b) radiation protection;
(c) familiarity with the reactor systems;
(d) engineering support (e.g. physics, instrumentation, chemical, civil, electrical and mechanical engineering);
(e) quality assurance and quality control;
(f) waste management;
(g) physical protection; and
(h) project management.

7.3 Specialized expertise may be necessary in other areas such as:

(a) dismantling and demolition;
(b) decontamination;
(c) robotics and remote handling; and
(d) fuel handling.

7.4. The safety assessment should consider the consequences of there being insufficient personnel with plant specific expertise. It would be of benefit to make use of personnel with experience in both operation and decommissioning.

7.5. In some cases contractors may be used to carry out all or some aspects of decommissioning. This is likely to occur when decommissioning is deferred or when plant personnel may not have the required expertise. Financial considerations may also require a greater use of contractors. Examples of such activities include the use of specific decontamination processes and dismantling/demolition activities. Appropriate levels of control, supervision and training should be provided to ensure safety.

7.6. All persons involved in decommissioning activities should be made familiar with the reactor site and the safety procedures for the safe and effective conduct of their duties. Specialized training may be needed in certain areas of work. For some activities, the use of mock-ups and models in training can improve efficiency and safety.

7.7. Basic requirements for a training programme and for refresher training for decommissioning activities should be described in the decommissioning plan [21].

ORGANIZATION AND ADMINISTRATIVE CONTROL

7.8. The organizational structure to be employed during decommissioning should be described in the decommissioning plan. In the description of the organizational structure, there should be a clear delineation of authorities and responsibilities amongst the various units. This is particularly necessary when the operating organization uses outside contractors. The organizational structure should ensure that the quality assurance review function is independent of the unit directly responsible for accomplishing the decommissioning activities.

7.9. Administrative measures stemming from the operational phase of the installation may be relevant during decommissioning. These measures should be reviewed and modified to ensure that they are appropriate to the decommissioning. The requirement for additional measures should be addressed. The administrative control measures may be required to be endorsed by the regulatory body.

7.10. A team composed of decommissioning specialists and appropriate site personnel should be formed to manage the decommissioning project. Although new competences may be required for the decommissioning phase, attention should be given to the retention of key personnel who are familiar with the installation during its operational phase. Since deferred decommissioning may continue for several decades, it is essential to document the historical knowledge represented by personnel associated with the reactor installation before final shutdown. This information should be accessible to decommissioning workers for use during active decommissioning phases.

7.11. In order to control all decommissioning activities, the operating organization should document and implement appropriate management systems. An example of such documentation is provided in Annex II.

RADIATION PROTECTION

7.12. The radiation protection programme should ensure that radiation protection is optimized and that doses are kept within appropriate limits. Although the principles and aims of radiation protection during operations and during decommissioning are fundamentally the same, the methods and procedures of implementation of the radiation protection may be different. During decommissioning special situations may need to be considered, which may require the use of specialized equipment and the implementation of certain non-routine procedures.

7.13. With respect to the need for radiation protection during decommissioning, certain points should be considered, such as:

(a) use of protective equipment for shielding, to limit internal and external exposure, and to minimize doses, e.g. leaded blankets, tents, local ventilation and filtering systems;
(b) having the appropriate number of skilled radiation protection personnel to assist in ensuring the safe conduct of the decommissioning tasks;
(c) ensuring that the decommissioning personnel have the appropriate skills, qualifications and training with respect to radiation protection techniques and requirements;
(d) good housekeeping practices to reduce doses and to prevent the spread of contamination;
(e) zoning of the reactor installation as a function of the levels of radiation and contamination, as well as appropriate rezoning as decommissioning work proceeds, according to the radiological hazards involved;
(f) ensuring an adequate system in which doses to workers and the public are kept as low as reasonably achievable; and
(g) documentation of all radiation protection measures and survey results.

7.14. The radiation protection programme should be clearly set out in the decommissioning plan. Those involved in its execution should be properly trained and have access to appropriate equipment for carrying out radiation surveys, including equipment for measuring external dose rates and surface contamination levels and for sampling air concentrations.

7.15. All decommissioning work should be planned and carried out using work order procedures and radiation work permits, with adequate involvement of radiation protection expertise to determine the required radiation protection measures. Moreover, the promotion of awareness of safety issues should be accorded high emphasis in planning and implementation. Those charged with the day to day responsibility for radiation protection should have the resources, access to decommissioning management and independence necessary to effect an adequate radiation protection programme.

ON-SITE AND OFF-SITE RADIOLOGICAL MONITORING

7.16. The decommissioning plan should specify the requirement for on-site and off-site monitoring during decommissioning. On-site monitoring should provide information to identify and assist in mitigating the radiological hazards. It should also be used in the planning of specific decommissioning activities. It should ensure that all potential

release points are monitored. On-site monitoring should consist not only of personnel monitoring but also of spatial monitoring for airborne contaminants, such as, having:

(a) appropriate monitoring equipment for dose rate and contamination surveys for workplaces, components and materials during decontamination, dismantling and handling;
(b) appropriate monitoring protocols and equipment for packaging and handling of radioactive waste within the site, as well as for transportation of the waste off-site;
(c) appropriate monitoring equipment for airborne contaminants;
(d) appropriate monitoring equipment for timely screening of large quantities of low level radioactive material for clearance purposes; and
(e) appropriate equipment and protocols to monitor the distribution of radionuclides in the installation.

7.17. The off-site monitoring programme inherited from the operational period will require modification appropriate to the conditions existing during decommissioning. Discharges of radionuclides via airborne and liquid pathways should be controlled, monitored and recorded, as required by the regulatory body or other relevant competent authority. Relevant recommendations are provided in Refs [11, 12, 22].

7.18. On-site and off-site monitoring, radiation and contamination surveys, as well as safety analyses and assessments, should be used to gauge the expected and actual degree of safety associated with decommissioning activities.

WASTE MANAGEMENT

7.19. A waste management plan, part of the decommissioning plan, should consider the different categories of waste produced during decommissioning and aim at the safe management of such wastes.

7.20. Consideration should be given to optimizing waste management and minimizing cross-contamination and secondary waste generation. The different categories of waste should be managed through pathways that are proven to be adapted to their characteristics and toxicities (radiological and non-radiological). Guidance on predisposal management aspects for radioactive waste is given in another publication issued [2].

7.21. Significant reductions in volumes of radioactive waste can be achieved through decontamination programmes, controlled dismantling techniques, contamination

control, sorting of waste materials, effective processing and, in some cases, administrative controls or internal audits. Reuse and recycle strategies have the potential of reducing the amounts of wastes to be managed. Similarly, the release of low activity materials from regulatory control (clearance) as ordinary waste or for reuse and recycle can also substantially reduce the amount of material which has to be considered waste.

7.22. The radiation exposure to workers and the public may vary according to the waste minimization strategy. An integrated approach should be used to balance waste minimization goals with the objective of keeping radiation exposures as low as reasonably achievable.

7.23. The waste management plan should address the question whether existing waste management systems are capable of coping with anticipated decommissioning waste that arises during decontamination, dismantling and demolition. If not, new facilities may have to be provided.

7.24. Where disposal is considered and no suitable waste disposal sites are available, the following decommissioning options should be evaluated in the preparation of the decommissioning plan:

(a) preparing and maintaining the installation in safe enclosure;
(b) dismantling the installation and storing the generated waste in appropriate temporary waste storage facilities; or
(c) conversion of the entire installation or a part of it into a storage or disposal facility.

7.25. In managing the waste from decommissioning, several factors should be considered. These include:

(a) the amount, category and nature of the waste that will be generated during decommissioning (relatively large quantities of radioactive waste may be generated in a short time);
(b) the possibilities for removal of waste from the regulatory control regime;
(c) the possibilities for the reuse and recycling of materials, equipment and premises;
(d) the generation of secondary waste in the decommissioning process and its minimization to the extent practicable;
(e) the presence of non-radiological hazardous materials, e.g. asbestos;
(f) the availability of waste recycling or treatment plants, storage facilities and disposal sites;

(g) any special requirements for the packaging and transportation of radioactive wastes, e.g. activated materials;
(h) the traceability of the origin and nature of the wastes arising from the decommissioning process; and
(i) the potential impact of the wastes on the workers, the public and the environment.

7.26. A large part of the wastes and other materials arising during the decommissioning process may be sufficiently low in activity concentration for regulatory control to be wholly or partly removed. Some wastes may be suitable for disposal in normal landfill sites while some materials, such as steel and concrete, may be suitable for recycling or reuse outside the nuclear industry. The removal of regulatory controls shall be done in compliance with criteria established by the national regulatory authority. Guidance on criteria for the removal of regulatory controls and on the management of the regulatory process for removal of controls is being developed in other IAEA safety standards.

7.27. Transport of radioactive waste off-site should conform to national regulations. International recommendations on transport of radioactive material are provided in Ref. [23].

7.28. The management and staff involved in the decommissioning project should be made aware of and trained, if necessary, in the methods of minimizing the waste generated in the tasks assigned. Such methods include installation of contamination control tents, containment of spills, and segregation of radioactively contaminated wastes from those wastes that are not radioactively contaminated.

EMERGENCY PLANNING

7.29. During the period of decommissioning, it may be necessary to develop, implement and maintain procedures to cope with abnormal occurrences. Site personnel should be trained in contingency procedures. Especially in cases where fuel has not been completely removed from the installation, contingencies should be incorporated into emergency planning in order to deal with accidents and incidents involving the fuel, such as the potential loss of coolant for the fuel if it is in a fuel pool.

PHYSICAL PROTECTION AND SAFEGUARDS

7.30. Appropriate physical protection and surveillance of the reactor site should be maintained during decommissioning [24]. This should be given particular considera-

tion if any phase of decommissioning is deferred for an extended period. If the reactor site contains materials subject to safeguards, the operating organization should adhere to the relevant international agreements and should comply with IAEA safeguards principles [25, 26].

QUALITY ASSURANCE AND DOCUMENTATION

7.31. An appropriate quality assurance programme should be planned and initiated by the operating organization before the decommissioning of a reactor commences. A description of the quality assurance programme, including a definition of its scope and extent, should be included as part of the decommissioning plan, and be put into effect before the start of decommissioning. All significant changes affecting systems, structures and components important to safety during the operation should be documented for use in the planning for decommissioning. Guidance on a quality assurance programme for decommissioning is given in Ref. [7].

7.32. The acquisition and retention of records and information relevant to the reactor site should be emphasized in the development of a quality assurance programme for decommissioning. Records should be retained as appropriate to meet the needs of future decommissioning and as dictated by national requirements. Where long periods of storage are anticipated, records should be periodically checked.

7.33. In the case of extended periods of safe enclosure, accurate and complete information relating to the locations, configurations, quantities and types of radioactive materials remaining at the reactor installation are essential and should be maintained. For deferred dismantling, the reports should specify the future maintenance and surveillance activities, as well as the need for the documentation of the results of these activities.

7.34. As discussed previously, the progress of decommissioning should be documented by the decommissioning operating organization (i.e. should be traceable). All radioactive materials that were present at the beginning of decommissioning should be properly accounted for, and their ultimate destination should be identified. After each phase of decommissioning, the operating organization should report to the regulatory authority detailing the disposal of the waste generated during the period. The report should also provide the current state of the installation or site and identify any anomalies observed during the phase. Moreover, information such as radiological surveys and personnel monitoring data should be reported to the regulatory body, as required. At the completion of decommissioning, a final decommissioning report including all elements of traceability should be prepared.

8. COMPLETION OF DECOMMISSIONING

8.1. On completion of decommissioning, appropriate records should be retained. In accordance with the national legal framework, these will be held and maintained for purposes such as confirmation of completion of decommissioning activities in accordance with the approved plan, recording the disposal of wastes, materials and premises, and responding to possible liability claims. The records to be assembled should be commensurate with the complexity of the installation being decommissioned and the associated hazard potential.

8.2. A final decommissioning report should be prepared, sustained by the records assembled and containing the following information:

(a) description of the installation;
(b) decommissioning objectives;
(c) radiological criteria used as a basis for the removal of regulatory controls from the equipment, buildings or site or for any other control regime approved by the regulator;
(d) description of the decommissioning activities;
(e) description of any remaining buildings or equipment not decommissioned or partially decommissioned;
(f) final radiological survey report;
(g) inventory of radioactive materials, including amounts and types of waste generated during decommissioning and their location for storage and/or disposal;
(h) inventory of materials, equipment and premises released from regulatory control;
(i) structures, areas or equipment designated for restricted use or properly covered by deed restrictions;
(j) summary of any abnormal events and incidents that occurred during decommissioning;
(k) summary of occupational and public doses received during the decommissioning; and
(l) lessons learned.

8.3. This report provides confirmation of the completion of decommissioning. Any remaining restrictions on the site should be registered as required by national regulations.

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Annex I

EXAMPLE OF THE CONTENTS OF A FINAL RADIOLOGICAL SURVEY REPORT

INSTALLATION NAME

INSTALLATION DESCRIPTION
Type and location of installation
Site description
Ownership
Installation description proper

BACKGROUND
Reason for decommissioning
Management approach

OPERATING HISTORY
Licensing and operations
Processes performed
Waste disposal practices

DECOMMISSIONING ACTIVITIES
Objectives
Results of previous surveys
Decontamination and dismantling procedures

FINAL SURVEY PROCEDURES
Sampling parameters
Background/baseline levels identified
Major contaminants identified
Release guidelines established
Equipment and procedures selected
Instruments and equipment
Techniques of instrument use
Procedures followed

SURVEY FINDINGS
Summary of findings
Techniques for reducing/evaluating data
Statistical evaluation

Comparison of findings with guideline values and conditions
Assessment of acceptability

SUMMARY

ATTACHMENTS
Detailed survey data with drawings

Annex II

EXAMPLE OF DOCUMENTED PLANS AND MANAGEMENT SYSTEMS FOR IMPLEMENTATION OF DECOMMISSIONING

1. The final decommissioning plan.

2. A project quality assurance programme. This may include sections on:
   (a) the site quality and environmental management systems;
   (b) a description of the site organizational structure;
   (c) procedures for the management of documentation (including records);
   (d) procedures for the management of decommissioning and support activities; and
   (e) procedures for the management of safety.

3. Documentation supporting the project quality assurance programme. This may include details of how all statutory and regulatory requirements (e.g. site licence compliance) are addressed and who is responsible for ensuring compliance.

4. The safety assessment. This is updated as necessary following procedures described in the quality assurance programme.

5. Documentation supporting the safety assessment. This may include:
   (a) a listing of conventional and radiological hazards which shows how each hazard will be managed;
   (b) an essential maintenance schedule which details plant maintenance necessary to comply with the safety assessment; and
   (c) a plant systems status schedule covering:
      (i) operational status;
      (ii) isolation status;
      (iii) dismantling (decommissioning status); and
      (iv) disposition status (removed, transferred, disposed of, etc.).

   This supporting documentation needs to be updated as necessary following procedures described in the quality assurance programme.

6. Procedures for dealing with and reporting abnormal events, incidents and emergencies.

7. A work breakdown structure and project implementation programme, which is updated as necessary following procedures described in the quality assurance programme.

8. Administrative control procedures for individual tasks, including:
   (a) procedures for the approval of:
      (i) technical proposals;
      (ii) radiological requirements;
      (iii) industrial safety;
      (iv) fire protection; and
      (v) security; and
   (b) procedures for the approval of individual task completion.

9. Procedures for the collection and maintenance of appropriate records in a secure and accessible manner, both during and after completion of decommissioning.

The compilation of these procedures into a ‘decommissioning operations manual’ is encouraged.

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